

Implications of AM for the Navy Supply Chain

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As the U.S. Navy continues to advance and become more integrated, our success relies on the balancing of the intricate interdependencies woven into the fabric of our Service. The underlying support structure that allows our Fleet units to perform their duties in support of U.S. national interests rely on the innovation and hard work of our uniformed and civilian personnel up and down the supply chain. That is why the

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strategic deployment of additive manufacturing (AM) machines throughout the supply chain, coupled with the right business model, is an imperative need in order to fully achieve the benefits of this technology.

The research and development communities within the Systems Commands (SYSCOMs), Office of Naval Research, together with private industry and other organizations, are leading a charge of rapid technological maturation. With the right operations plan that requires changes to our business decision modeling and the tools used to manage the supply chain, including Navy Enterprise Resource Planning (ERP), the Navy will be able to take full advantage of these technological advances. This is why the Naval Supply Systems Command

(NAVSUP) will play a significant role in planning to leverage AM's full potential.

Business Case Analysis

Once SYSCOMs have identified parts that can be produced by AM to a specified level of technical performance and within tolerances, a business case analysis (BCA) must be performed before a determination is made to build and supply via AM. For example, printing a wrench is technically easy from an AM perspective, but the cost and time to make that part by using AM, coupled with limited throughput, would not be cost effective, as the wrench is a ubiquitous item and cheap to mass produce. However, a more complex part with low inventory demand could be an excellent candidate. A cooperative effort

Table 1. Additive Manufacturing Business Model Factors

Incurred Costs	Cost Savings	Other Considerations
Material Cost: Cost of material to produce and cost of waste.	Inventory: No stocking requirement means no cost for shelf space, inventory management or personnel.	Lead Time: Clock starts from initiation of demand signal to a finished and usable part. Time savings in both Administrative and Procurement Lead Time (ALT/PLT).
Operations and Maintenance: Assigned share of cost to operate and maintain the system to produce that particular part; includes training of personnel.	Waste: No expired inventory, no over-buy; make what you need when needed.	Post-processing: Capacity to post-process at or downstream of PoM.
Post-processing: Cost to post-process a part, such as by finishing or coating it.	Shipping: Commercial versus organic, would decrease as the AM machine point of manufacture (PoM) is deployed closer or even at point of demand.	Performance: If a disparity exists between performance or service life of an AM as opposed to a traditionally manufactured part, would that be acceptable in that use case to the Fleet user?
AM Technical Data Package: There are unique aspects to developing a package suitable to a particular AM machine, such as topology, .stl file, or the electronic instructions or program to build the part. This cost may be nontrivial and would need to be amortized across a portion of a part's expected run.		Shipping Time (T_s): Transit time for the usable product to the end user.
Source Approval Process: Regardless of whether a commercial vendor or the government is building an AM part, it needs to be tested and certified, and there is a cost to doing so. A commercial vendor would amortize that into the per unit cost. For organically produced parts, the government could opt to absorb it.		Contracting: Appropriate contracts should be in place. Desire is to avoid writing up a purchase order/request every time a vendor gets an order to make an AM item.
Cost of the Capital Asset: The more capable an AM machine, the more it costs, upward of \$1M each in some cases. This also needs to be amortized.		
Intellectual Property: License or royalty fees incurred.		

to develop a standard BCA template, taking into consideration the parameters in Table 1, should be undertaken to reduce or eliminate variability in the decision-making process.

As can be seen, even quantitative measures, such as lead time, can take on a subjective measure of importance. The priority of the demand signal could act as a weighting factor to favor one option over another (i.e., shorter lead time but higher total cost) to automatically route the order to a Point of Manufacture (PoM) appropriate for that request. The bottom line is the business decision to adopt AM for a particular part should be made first, weighing the factors in Table 1, to ultimately determine if the return on investment and readiness improvements make it worthwhile. In October 2015, the U.S. Army Logistics Innovation Agency completed a study assessing BCAs for AM-produced parts. However, that study performed a large-scale analysis focused on any stocked item that could be made via AM, versus the more targeted and specific focus of lower demand parts within the Navy's efforts. Therefore, Navy BCAs should be done on a case-by-case basis to determine whether cost/time savings make sense for that particular part. At NAVSUP Weapon Systems Support (NAVSUP WSS), in cooperation with Penn

State Applied Research Laboratory's development of an AM Supply Chain Modeling and Simulation tool, an AM feasibility assessment was performed for 150 H-53 components. A BCA model could be tested on those items.

With reduction or elimination of the requirement to stock an item, at the very least at the wholesale level, the introduction of a direct to manufacture demand signal leads to a paradigm shift in Supply Chain Management (SCM) philosophy. To date, decisions to reorder have been based on predictive demand, force deployment, or in reaction to unplanned stockouts or significant fluctuations in demand. We could apply the concept of just-in-time (JiT) inventory to noncommercial items with low demand, greatly reducing or even eliminating the need to maintain a level of wholesale and possibly retail inventory.

JiT Inventory

Currently, when a demand signal is introduced to the system, this requisition goes through the ERP front-end processor before getting routed. The ERP Sourcing Module will then determine whether an order needs to be filled, killed or backordered. A second module captures data refreshing demand forecasts quarterly. Finally, a buy/repair module determines whether a new order from the vendor is necessary and informs the planner. The algorithms which drive the logic reside within each ERP module and dictate how much inventory needs to be kept on the shelf at the wholesale and

retail level and when to reorder. However, the lead time for manufacture is still a significant factor in inventory planning. Naval Aviation is suffering due to critical high-priority back-ordered parts that have grounded a significant number of our aircraft. Similarly, ship Casualty Reports of back-ordered extremely low-demand items reduce a ship's mission capability and take 1 to 3 years to fill.

One key advantage of AM is the potential for drastically reducing lead time to manufacture to possibly a mere 24 hours followed by some time to post-process if necessary. So the Logistics Information Technology business systems that manage the Navy's SCM will need to be configured to take full advantage of JiT.

Table 2. Aircraft Supported by NAVSUP WSS

F/A-18 A-D	E-2C	H-1	P-3	C-130
F/A-18 E/F	E-2D	H-53	P-8	AV-8
EA-18G	C-2A	H-60	V-22	EA-6B

where contractor logistics support is used, such as the E-6B and other trainer aircraft.

After a requisition hits ERP, that demand signal would get routed to the appropriate AM machine. The machine would report back to ERP when that part was built, burdened cost and how much raw feedstock was used, machine status, and

We could apply the concept of just-in-time inventory (JiT) to noncommercial items with low demand, greatly reducing or even eliminating the need to maintain a level of wholesale and possibly retail inventory.

ERP considers Administrative Lead Time (ALT) and Procurement Lead Time (PLT) when deciding whether to re-order. ALT is the time to put out a contract or purchase order to a vendor, and PLT is the time between award and/or obligation and first delivery. AM could reduce that time significantly if the right contract vehicles were in place, the business logic appropriately modified, and AM machines were strategically deployed at the critical points in the supply chain.

For example, PoM has never been a real consideration in making a business decision in Navy Supply, since we usually are limited to one vendor, or more rarely two vendors, approved and/or on contract to make a part or subassembly; the system doesn't care where the part originates (PLT much greater than shipping time or T_s). Once the digital AM thread is established and secure, demand signals for a new subset of AM producible parts should be routed to a location most geographically suited to manufacture and ship that part based on T_s plus the capacity to post-process the part at or downstream of the PoM. A systems monitor would be alerted as to the build order, plus the part's destination, and would prepare the shipping container and materials in advance of completion.

Updated Process Flow

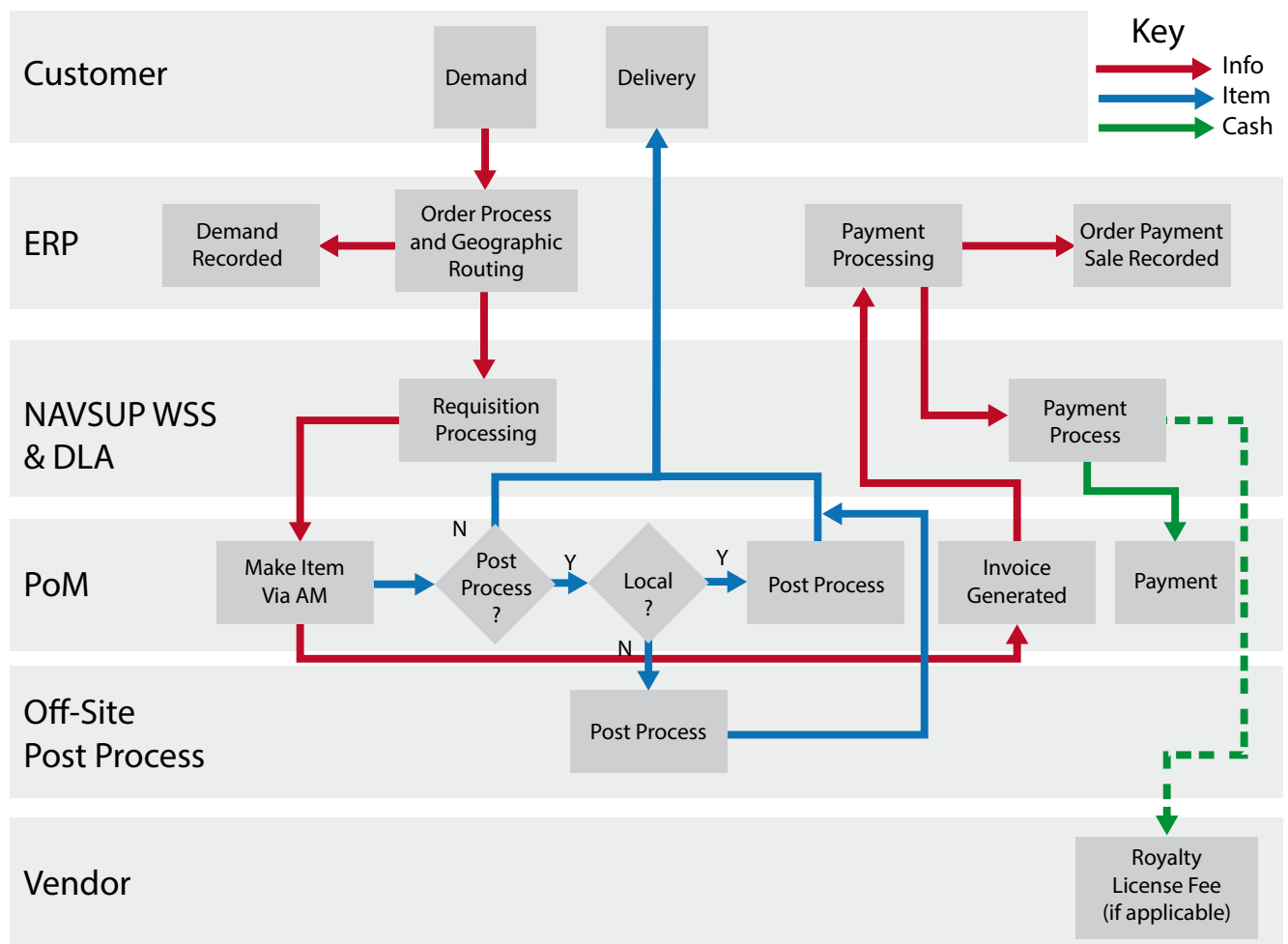
A future order flow for ERP incorporating AM could follow the diagram in Figure 1. This flow currently is limited to certain type model series (Table 2), and does not include aircraft

expected shipping date. The ERP Module records the demand. Finally, AM feedstock, in the form of powders or polymers, is continuously assessed within ERP across the entirety of the supply chain to ensure sufficient stock is available.

To maintain proper cost accounting, this evolution should result in a series of invoices that direct the appropriate financial resources or charges levied as necessary. This flow should be more or less the same as it is now when a Fleet Readiness Center completes work on a Depot Level Repairable and either sends it to a Fleet unit or back to a system stock point, but it must become more automated. The receiving unit pays a burdened rate for the AM-produced part, including materials, shipping, royalties and all other apportioned costs.

A variation on the updated process flow introduces the complexities of a hybrid model in cases when the the machine is government owned and operated but a vendor retains data rights. In this case, NAVSUP WSS or the Defense Logistics Agency could pay the vendor a license fee after the part is manufactured. Establishing a long-term contract with a vendor specifying such fees for a specified item would eliminate the need for individual purchase orders, avoiding the time and cost associated with cutting that document. Vendors simply would be notified when an order for one of these parts comes through and then again when the part is made. The government could then on an agreed-upon

Figure 1. Updated Navy Enterprise Resource Planning Order Flow



periodic basis pay the vendor what is owed, and ERP would record everything. This shares some similarities with current contractual constructs for Performance-Based Logistics (PBL) efforts in which the government pays a vendor to maintain a level of readiness, not for individual procurement or repair orders.

The model becomes much simpler when the order goes directly to a vendor. Once a vendor has a working machine and sufficient feedstock, each government purchase order should look the same. A long-term Indefinite Delivery Indefinite Quantity (IDIQ) construct would be used, delineating a single base price for manufacture and shipping while allowing for small annual increases due to inflation.

Constraints

As laid out, there are several major areas throughout the supply chain that will require changes or upgrades prior to implementation, running the gamut from technical, algorithmic, logical, to legal and contractual. They should not be insurmountable, but identification of all the constraints is critical to successful AM integration into SCM.

For example, IDIQ contracts and ERP compliance require that we identify which items we intend to buy and approximate quantities over the ordering period. AM makes the process more open-ended, although quantities for expected demand should not vary significantly, at least in the short run; AM is only supplanting a previous method of manufacture for a part, not increasing the draw. The government generally is required to state ahead of time the minimum number of parts it agrees to purchase over the life of the contract, and the vendor needs to agree to the turnaround times, which would be significantly shorter than those of traditional manufacturing.

Delivery Orders (DOs) can take months to organize and award, pricing may vary based on tiered pricing tables, and a DO is not awarded until all the funds for full execution of that DO are in place and ready for obligation. In the proposed model provided, an overarching purchase contract would need to exist under which the government agrees to pay a vendor each time a part is ordered, whether it's "customer direct" to the vendor each time a part is made, or a license fee when the part is manufactured organically, with each DO cut automatically without human intervention. ERP does have


provisions for PBLs, but not necessarily a “pay for XX quantity of and unknown mix items at the end of period YY” outside of that construct. The government would award a contract based on a pre-determined amount of parts. Plus, that is very difficult to do outside of a cost type—PBL construct. At the end of each fiscal year, the contract could be reconciled based on the number of parts ordered as compared with how much was initially obligated. If demand significantly exceeds expectations, ERP would notify the contracting agency so that additional funds could be obligated if so desired.

As for licensing and royalty contracts, this has not been implemented on the proposed scale before. Although very rarely used, Federal Acquisition Regulation 31.109 covers the negotiation of Advance Agreements, while 31.205 discusses how to handle the cost element, and 27.202 goes to the specifics of reporting, adjudication and the Notice of Government at a licensee. The government and vendor should negotiate a fee that is a fair percentage of the AM production cost for that particular part. The first set of these contracts should be done with great care, as that negotiated percentage could set precedent for all future similar contracts.

Summary

Once issues of qualification and certification are overcome for a sufficient population of parts, AM has the potential to improve the Navy’s SCM and response in several ways:

- Shorter lead times
- Greater capacity to absorb positive and negative demand shocks
- Lower inventory carry costs
- Exact and near-real time correlation between supply and demand
- Reduced backorders

As with any new technology, understanding AM’s benefits, capabilities and limitations will be crucial to successful implementation. Both the government and our vendors will have to change mindsets, process and procedures to achieve AM efficiencies. Failing to adjust business practices and acquisition rules to AM’s unique aspects will result in our missing out on the revolutionary advantages the technology offers us to keep our ships sailing and our planes flying. 

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